

Reliability of measures of gait performance and oxygen consumption with stroke survivors

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Abstract—This study assessed the reliability of gait performance with concurrent measures of oxygen consumption (VO_2) in stroke survivors (SS). Nine male SS (60.00 ± 15.08 yr) had a recent history of stroke (44.56 ± 51.35 days since the stroke) and were receiving rehabilitation. Four had a right cerebrovascular accident (CVA), and five had a left CVA. Subjects walked without assistance, although three used a single cane to complete the test. Within 30 minutes, subjects completed two trials of a 5 min walk while walking back and forth on a 5 m walkway wearing a portable gas analyzer to collect samples of gases. The intraclass correlation coefficient (ICC) was used to assess reliability. The ICC for gait energy expenditure, walk distance, gait speed, and gait energy cost were 0.64, 0.97, 0.95, and 0.97, respectively. Assessment of gait performance with concurrent measures of VO_2 is a reliable procedure with SS.

Key words: gait performance, oxygen consumption, reliability, stroke.

INTRODUCTION

Mobility is often significantly affected by cerebrovascular accident (CVA). Hence, a principal goal of rehabilitation for patients who survive a CVA is to target mobility and independence and to recover function. Residual motor deficits, especially those linked to gait,

impose further health-related risks and contribute to increased morbidity associated with this chronic condition. This population also has poor aerobic function, which may be further aggravated by a preexisting cardiovascular condition, such as hypertension, congestive heart failure, peripheral vascular disease, or pulmonary and metabolic diseases [1–3]. Energy expenditure (EE) required to perform routine ambulation is elevated approximately 1.5- to 2.0-fold in hemiparetic stroke patients compared to normal control subjects [4].

Abbreviations: ANOVA = analysis of variance, CVA = cerebrovascular accident, D = distance, EE = energy expenditure, HR = heart rate, HVAMC = Houston Veterans Affairs Medical Center, ICC = intraclass correlation coefficient, S = speed, SDD = smallest detectable difference, SEM = standard error of the measurement, SS = stroke survivors.

This material was based on work supported partially by the Houston Veterans Affairs Medical Center: Rehabilitation Research and Development Center of Excellence on Healthy Aging with Disabilities and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brazil.

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Increased energy demand reduces movement, favoring further decline in cardiopulmonary fitness and increasing disuse atrophy and weakness, which further impairs function [5]. Despite this, rehabilitative interventions usually fail to emphasize the need to improve or to prevent further deterioration of the ability to generate aerobic work, especially for patients in the acute stages of recovery from a stroke. The lack of aerobic training for these patients may be justified by the lack of strong evidence to suggest that aerobic exercise training can reduce the high EE or cardiovascular demands of walking in this population. Moreover, these patients are considered high risk for new cardiovascular events, and few studies define exercise parameters or the safety of this mode of rehabilitation for this population. Cardiovascular comorbidity is a significant health concern in approximately 75 percent of the patients who experience a stroke, and cardiac disease remains the leading cause of death in individuals who are long-term stroke survivors (SS) [6].

Few studies have actually assessed aerobic function, especially with subacute SS, because of the lack of protocols and guidelines [5–8]. Measurement of aerobic capacity by bike or treadmill protocols with actual measures of peak oxygen consumption (VO_2) during maximal effort is expensive, requires specialized personnel, and demands time. This population of SS is considered to be high-risk for exercise stress testing given the frequent association between CVA and hypertension. Furthermore, the practicality of maximal aerobic stress tests in this population may be questionable, depending upon the magnitude of the motor and neurological impairment.

Indirect assessment of aerobic function with SS has been performed by measures of endurance obtained with timed walking tests, such as the 5 min and 6 min walks [8,9]. Timed walking tests have been developed to assess endurance with patients who have different disabling conditions, and the psychometric qualities of these tests, such as reliability and validity, have been reported [10,11].

More recently, the use of portable gas analyzers has allowed the assessment of VO_2 during functional activities. Patients can carry these analyzers on their back while performing functional tasks. Measurement of VO_2 during functional activities might indicate more appropriately the patient's capacity to generate aerobic work.

Neuromotor recovery is more pronounced during the first 3 months after a stroke and contributes to the variability of outcomes during this period. Any tool developed to

evaluate outcomes with the neurologically impaired population must demonstrate stability over time so that the observed scores are as close as possible to the true scores. Therefore, the main objective of this paper was to assess the reliability of gait performance with concurrent assessment of VO_2 with the use of a portable gas analyzer in a group of SS.

METHODS

Subjects

Ambulatory SS were recruited from a sample of convenience admitted to the Rehabilitation Service at the Houston Veterans Affairs Medical Center (HVAMC). Participants had a stroke less than 4 weeks before entering the study, and they provided written informed consent before participating. This study was approved by the Institutional Review Board for Human Subject Research for Baylor College of Medicine and Affiliated Hospitals.

Instrumentation

We obtained measurement of VO_2 with an Aerosport portable gas analyzer, model KB1-C. This is a lightweight (1.25 kg) portable system that comprises a face mask for collecting expired air, a pneumotach, sensors for analyzing oxygen (O_2) and carbon dioxide (CO_2) content of expired air, a heart rate (HR) monitor with a chest strap transmitter worn around the chest, and a battery pack. The KB1-C system performs O_2 and CO_2 analysis continuously using a patented system called Electronic Variable Sampling. As air is exhaled through the pneumotach, a proportional microsample is drawn off into a mixing chamber inside the unit. The O_2 concentration is measured with a galvanic fuel cell, and the CO_2 concentration is measured by nondispersive infrared analysis. These are the same methods used in conventional metabolic measurement systems. Expired flow is measured with a flat-plate orifice pneumotach, and ventilatory volume is calculated by digital integration. VO_2 and rate of carbon dioxide production (VCO_2) are calculated according to standard equations for indirect calorimetry.

Before each assessment, the pneumotach was calibrated with a 3 L calibration syringe. The gas analyzers were calibrated according to the manufacturer's specifications with the use of a calibration gas of known O_2 and CO_2 composition [12 percent O_2 and 5 percent CO_2 , and

balance nitrogen (N_2)). The KB1-C system was set to sample data every 20 s for ventilation, fractions of inspired O_2 and expired CO_2 , HR, respiratory exchange ratio, VO_2 , and VCO_2 . Participant information such as age, gender, height, and weight was entered in the portable gas analyzer before each measurement

Validation of the KB1-C system has been reported against a standard metabolic gas analyzer in which patients with paraplegia exercising to exhaustion during arm crank ergometry and with nondisabled subjects running to exhaustion on a treadmill (coefficient of determination of 0.94 for fractional expired oxygen) [12]. The KB1-C has also been validated against a criterion Douglas bag system during cycle ergometry [13]. In this latter study, the validity of the system was acceptable for measuring O_2 uptake in the 1.5 to 3.5 L/min range [13]. There are no reports on the validity of this system for the level of VO_2 observed in this present study.

Protocol

Before beginning the test, each subject was instructed to walk back and forth at a usual gait speed, on a 5 m walkway for 2 min to become acquainted with the procedure. The subject was then allowed to rest for 6 min.

The subject was then fitted with the portable gas analyzer, a facemask, and a chest band HR transmitter. The participants were asked to walk on the 5 m walkway for a total time of 5 min. The floor was marked in 1 m intervals, and the subjects were asked to walk back and forth at their usual gait velocity throughout the test. We used a stopwatch to measure the walking time.

After this first trial, the mask was taken off and the information recorded was printed. The participant was allowed to rest for at least 10 min before performing the second trial. The portable gas analyzer was recalibrated, the facemask was repositioned, and the subject then completed the second trial.

The variables of interest were rate of VO_2 during the 5 min walk, which was called EE, walk distance (D), gait speed (S), and gait energy cost (C). EE was calculated by averaging three samples of VO_2 recorded every 20 s each minute during the 5 min walk. Data were recorded in milliliters of O_2 per kilogram of body weight per minute walked ($mLO_2/kg/min$). D was recorded in meters and was the total distance covered in 5 min. Since body weight contributes to the expression of VO_2 , VO_2 is reported relative to body weight. Participants were weighed on a stand-on digital scale (Scale-Tronix 5005)

immediately before the initiation of the protocol. Weight was assessed in kilograms with participants dressed and with shoes on, the same way they performed the tests.

Measurement of gait speed (m/s) was obtained by dividing the walk distance by the time walked in seconds for the entire 5 min. Cost was obtained by dividing the values of VO_2 sampled during the 5 min walk by the speed values in meters per minute.

Although walk performance has been reported based on a 6 min walk test [2,9,11], we used the 5 min walk considering that the population studied is more acutely compromised and might be more limited compared to subjects with a chronic stroke. The 5 min walk as an indicator of gait endurance has been used with patients with different levels of neurological impairment [8,10].

The use of a 5 m walkway to assess gait performance was selected because it required different levels of neuromuscular integrity, such as the ability to change gait acceleration and to turn, which may impact walking performance. Moreover, because subacute SS may be discharged home or to skilled facilities, assessment of gait performance in such a short track might represent more of the requirements on discharge.

Statistical Analysis

Data are presented as means and standard deviations (SDs). The main item of interest in this study was the relationship between the paired measurements EE, D, C, and S during the 5 min walk for the same patient. We analyzed the data using repeated measures analysis of variance (ANOVA) with the trial as the independent variable and the patient as a random effect. The intraclass correlation coefficient (ICC), which is a measure of correlation that considers variance, describes the agreement between the repeated measures. The model $ICC_{3,1}$ was chosen because we were looking for the stability of the measures based on one assessment. The ICC was calculated as described by Fleiss and Shrout and is defined mathematically as the ratio between the variance component obtained between subjects minus the residual error, divided by the between subjects variance [14].

We used the standard error of the measurement (SEM) to indicate absolute reliability and calculated it as the square root of the absolute error variance [15,16]. We also calculated the smallest detectable difference (SDD) for the measurements. This SDD is a clinically relevant measure because it suggests the change that might be expected because of an intervention rather than sampling

error at a level of statistical significance of 0.05 level. The SDD is the 95 percent confidence interval (CI) of the SEM multiplied by the square root of 2; i.e., $SDD = \pm 1.96 \times \sqrt{2} \times SEM$. Thus, we calculated the smallest change between two independent measurements for the outcomes of interest [17].

RESULTS

Nine male subjects were recruited to participate in this study. **Table 1** depicts demographics, such as age, height, weight, number of days since the stroke, type and location of injury, comorbidity, and medication. Subjects had a mean age of 60.00 ± 15.18 years. The mean time since the CVA was 44.56 ± 51.35 days. Five had a right CVA, and four had a left-sided CVA. All participants were ambulatory and clinically in stable condition. Three participants used a single cane to complete the test, and one participant used a wheelchair for long distances.

In **Table 2**, the values for each outcome variable are shown separately for each subject, across trials. The ANOVA indicated that the mean values for EE, D, C, and S were not different between trial 1 and trial 2: $6.75 \pm$

1.24 versus 6.93 ± 1.44 mL O_2 /kg/min ($F_{1,8} = 0.23$, $p = 0.64$), 152.94 ± 60.55 versus 158.06 ± 57.21 m ($F_{1,8} = 2.38$, $p = 0.16$), 0.25 ± 0.11 versus 0.24 ± 0.09 mL O_2 /kg/m, ($F_{1,8} = 3.52$, $p = 0.10$), and 0.51 ± 0.20 versus 0.53 ± 0.19 m/s ($F_{1,8} = 2.46$, $p = 0.16$), respectively. **Table 3** depicts the reliability index obtained for each outcome variable (ICC), SEM, and SDD.

DISCUSSION

The purpose of this study was to evaluate the reliability of gait performance with simultaneous measurement of VO_2 with individuals who had had a recent CVA. The ICCs obtained with this study indicated that the reliability of VO_2 during walking (EE) is modest, but can be excellent when its assessment is normalized by walking velocity, which is the gait energy cost.

For walking in normal individuals whose ages ranged from 20 to 80 years old, the reported gait EE is 12.01 mL O_2 /kg/min [18]. Previous studies involving subacute and chronic SS reported gait EE values of 8.9 mL O_2 /kg/min [19], 6.6 mL O_2 /kg/min for more impaired SS, and 8.15 mL O_2 /kg/min for less impaired SS [8]. In our study, the mean EE

Table 1.
Participants' characteristics.

Subject	Age	Height	Weight	No. Days Since Stroke	Type of Injury	Location	Comorbidity	Medication
1	69	185.90	101.60	7.00	H	R parieto-occipital cortex	CAD, Afib, MI, CHF	1,2,4,5,9
2	51	176.00	83.90	153.00	I	R subcortical	HTN, GI	3,4
3	73	108.10	71.70	6.00	I	L subcortical	CAD, PVD, CABG	4,9
4	69	173.00	79.80	2.00	I	R subcortical	HTN,	4,9
5	27	188.00	80.70	43.00	I	L hemisphere	—	9
6	57	175.00	98.00	28.00	I	L cortical	—	9
7	63	183.00	90.70	45.00	I	L subcortical	—	4,9
8	54	163.00	74.40	103.00	I	R frontal	—	8,9
9	77	177.80	83.50	14.00	I	L frontal	CAD, HTN, GI	1,4,8,9
Mean	60.00	169.99	84.92	44.56	—	—	—	—
SD	15.18	24.33	10.03	51.35	—	—	—	—

Afib = atrial fibrillation	HTN = hypertension	TIA = transitory ischemic attack	5 = nitrate
CABG = coronary artery bypass grafting	I = ischemic	SD = standard deviation	6 = antiarrhythmic
CAD = coronary artery disease	L = left	1 = beta-blocker	7 = digitalis
CHF = congestive heart failure	MI = myocardial infarction	2 = diuretics	8 = alpha-blocker
GI = glucose intolerance	PVD = peripheral vascular disease	3 = ACE inhibitors	9 = other
H = hemorrhagic	R = right	4 = calcium channel blocker	

Table 2.

Individual scores for each variable evaluated in both trials.

Subject	EE		D (m)		C		S (m/s)	
	(mLO ₂ /kg/min)				(mLO ₂ /kg/m)			
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
1	5.72	5.58	167.00	153.00	0.17	0.18	0.56	0.51
2	9.46	8.96	128.50	145.00	0.37	0.31	0.43	0.48
3	6.44	8.68	269.00	275.00	0.12	0.16	0.90	0.92
4	5.91	5.03	130.00	135.00	0.23	0.19	0.43	0.45
5	5.85	5.21	220.00	219.00	0.13	0.12	0.73	0.73
6	6.14	6.75	69.00	81.00	0.45	0.42	0.23	0.27
7	7.74	6.87	144.00	141.50	0.27	0.24	0.48	0.47
8	7.43	7.52	150.00	158.00	0.25	0.24	0.50	0.53
9	6.05	7.79	99.00	115.00	0.31	0.27	0.33	0.38
Mean	6.75	6.93	152.94	158.06	0.25	0.24	0.51	0.53
SD	1.24	1.44	60.55	57.21	0.11	0.09	0.20	0.19
p Value	0.64	—	0.16	—	0.10	—	0.16	—

EE = gait energy expenditure
D = walk distance
S = gait speed

C = gait energy cost
SD = standard deviation

across trials was 6.84 mLO₂/kg/min. This value suggests that the population evaluated in this study was comparable to the more impaired SS and demonstrated a level of VO₂ during walking that was about half of the normal values.

In a previous generalizability study conducted in our laboratory involving 40 healthy individuals (ages ranged from 18 to 53 years), we observed that this portable gas analyzer generated a reliability coefficient of 0.93 for EE. In the present study, the reliability index obtained with SS was lower than the one observed for healthy individuals (ICC_{3,1} = 0.64). Measures of VO₂ while subjects walked

are prone to variability because they can be influenced by the walking speed and by the subject's size [21]. The variability in this measure might be even more evident in a population such as SS because of the impaired gait and different characteristics of the gait, such as asymmetry and reduced stride lengths.

When the VO₂ (EE) was analyzed reflecting the efficiency of walking (gait energy cost), that is, normalizing the VO₂ by the walking velocity, the reliability index increased to 0.95. This indicates, indeed, that gait speed affects the variability of VO₂ and, therefore, should be included in the calculation of measures of VO₂ during walking. The mean distance covered during the 5 min walk between trials was 155.5 = meters with preferred gait speed, and the reliability of this measure was high (ICC_{3,1} = 0.97). A walk distance of 144 m has been used to classify SS as moderately impaired on a 6 min walk [22]. If we extrapolate this value to a 5 min walk, a moderate impairment would be equivalent to a walk distance of 120 m. On admission, subacute SS walked a mean distance of 53.93 m ± 49.7 m, ranging from 1 m to 162 m, during a 5 min walk [23]. In this study, two out of nine participants walked less than 120 m in both trials. Therefore, our group ranged from moderate to less than moderate impairment while walking.

The gait speed of SS demonstrates substantial variability, depending on when the assessment was conducted during recovery, the amount of compromise, and

Table 3.

Reliability indexes.

Measure	ICC _{3,1}	SEM	SDD
EE (mLO ₂ /kg/min)	0.64	0.80	2.22
D (m)	0.97	6.92	19.18
C (mLO ₂ /kg/m)	0.95	0.02	0.06
S (m/s)	0.97	0.02	0.06

ICC_{3,1} = intraclass correlation coefficient (model)
SEM = standard error of measurement
SDD = smallest detectable difference ($1.96 \times \sqrt{2} \times SEM$)
EE = energy expenditure (gait)
D = distance (walk)
C = cost (gait energy)
S = speed (gait)

the length of the track used [22,24,25]. Nevertheless, gait speed is a well-accepted indicator of neurological recovery in SS [22,24]. The mean speed between trials in this study was about 0.52 m/s, which, according to Wade et al., is a normal walk speed for SS [25]. Therefore, the use of a short walkway does not seem to underestimate the values for walking speed. The reliability of speed assessment in this study was excellent ($ICC_{3,1} = 0.97$).

Before test initiation, participants were instructed to walk back and forth on the 5 m walkway for 2 min to get used to the procedure and to decrease variability during the testing because of the lack of familiarity with the process. However, the participants tended to perform better during the second trial, although the instructions to perform the test were not altered between trials. The participants walked longer and faster, but tended to be more efficient (lower costs) in the second trial. This trend suggested that the participants walked more naturally and closer to their optimal performance at preferred walking velocity during the second trial.

We also used measures of SEM to indicate absolute reliability that can be expected in an individual's performance. The SEM values for each outcome variable were small enough to demonstrate that the measurements are stable over time.

We reported an analysis of the SDD for each outcome variable to illustrate that the measure of absolute reliability can also be used to indicate the size of change that is expected because of an intervention as compared to changes just related to sampling error. In our sample, a change between two consecutive measures of VO_2 of more than 2.22 mL O_2 /kg/min could be considered a meaningful change. A meaningful change in walk distance should be higher than 19.18 m. For cost and speed, changes should be more than 0.06 mL O_2 /kg/m and 0.06 m/s, respectively.

The number of turns expected in such a short walkway (5 m) is known to affect both walking distance and velocity. Furthermore, more turns may have differential effects on patients with varying levels of gait impairment. For example, a more severely compromised stroke survivor may take longer to turn (more steps) and probably use more oxygen in the process. However, gait performance based on a short distance may represent a patient's daily life more, considering that they are more often required to overcome short distances during the day when discharged from acute rehabilitation and sent home. With this study, we did not find any indication that

the 5 min walk completed on a 5 m walkway might have underestimated the participant's walk endurance or gait speed or that gait EE and gait cost were excessively scored, considering that the results are within the range for similar patients. Therefore, the use of a 5 m walkway to assess gait outcomes, such as endurance, EE, speed and energy cost, may be another possible choice to evaluate gait performance. Changes in acceleration accompanied by multiple turns may provide a more realistic estimate of walking required in daily life.

CONCLUSION

Since the sample size used was small, the generalizability of the results is limited. In addition, the KB1-C system still needs further validation while measuring low levels of VO_2 , similar to the ones observed here. However, this study indicates that same-day measures of gait performance obtained during a 5 min walk completed on a 5 m walkway are reproducible with ambulatory subacute SS and were similar to other studies reported. The variability of VO_2 during walking can be decreased by normalizing the oxygen values by the gait speed. One should examine the smallest detectable differences in clinical settings to sort out changes that may occur as a result of clinical interventions as opposed to changes secondary to natural recovery or the variability of the measure.

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Submitted for publication January 16, 2001. Accepted in revised form October 10, 2002.